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A Practical Statistical Model for Telecommunications Performance Uncertainty

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PREFACE

The work described in this report was performed by the Telecommunications Division of the Jet Propulsion Laboratory.

FOREWORD

The method described in this report has been approved by the Telecommunications Division Design Board of the Jet Propulsion Laboratory. It will be adopted as the official telecommunications link design criterion which supersedes all previous telecommunications link design criteria.

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ACKNOWLEDGMENT

The author wishes to thank R. P. Mathison and F. V. Stuhr for their many constructive comments.

ABSTRACT

In the design of its telecommunications systems, the Jet Propulsion Laboratory has used a deterministic worst case procedure and criterion to assess link performance uncertainties. Experience over many lunar and planetary flight projects has demonstrated that it is practical from the point of view of engineering and management. However, a chief disadvantage of the deterministic procedure is that no information is given about the likelihood of achieving the design value or any particular values. Without the probability function of achieving a particular performance value, cost tradeoff and risk assessment cannot be done quantitatively.

This report presents a practical method which we shall call the Probability Distribution Method (PDM). It is a statistical approach, rather than the current deterministic one, which will give the probability of link performance values, hence removing the chief disadvantage of the current practice. At the same time, PDM also aims at preserving all the advantages of the present design control procedure.

PDM does not in any way increase system capability. It does, however, allow optimal use of the system capabilities by improving the accuracy and completeness of the system model.

A PRACTICAL STATISTICAL MODEL FOR TELECOMMUNICATIONS PERFORMANCE UNCERTAINTY

I. INTRODUCTION

Successful scientific exploration of outer space and application benefits derived therefrom are vitally dependent upon reliable radio communication between spacecraft and ground stations. In the design of telecommunications systems, the Jet Propulsion Laboratory currently uses a deterministic worst case procedure and criterion to assess link design uncertainties. In using this so-called sum-of-adverse-tolerances procedure, it has always been the practice to assess adverse and favorable tolerances along with design value for each parameter in the telecommunication system; then compute the performance margin of the entire link by linearly summing in the dB domain the design values, the averse tolerances, and the favorable tolerances of all the parameters in the link. All of the uncertainties in component or subsystem design are included in the tolerances. Hidden pads or safety margins are specifically excluded from the design values. Then, if the overall link performance tolerance is determined by linearly summing all the individual tolerances, the criterion for an adequate system design margin is when the design performance exceeds the required performance by the overall system tolerance.

The telecommunications link performance adverse tolerance represents the accumulation of the extreme values of individual parameters in the link. This adverse tolerance represents the lower performance bound in the absence of failure. This is a very extreme condition that will occur with exceedingly small probability. It is, indeed, overly conservative and pessimistic to assume all the worst should happen at the same time. Furthermore, this sum-of-adverse-tolerances method provides no information about the likelihood for achieving the design value, the favorable and adverse tolerances, or any particular values. This is the major disadvantage of the current method. Without the probability function of achieving a particular design value, cost tradeoff and risk assessment cannot be done quantitatively. Although this sum-of-adverse-tolerances method has its disadvantages, experience over many lunar and planetary flight projects has demonstrated that it is practical from the point of view of engineering and management.

This report presents a practical method which we shall call the Probability Distribution Method (PDM). It is a statistical approach, rather than the current deterministic one, which will give the probability of link design values, hence removing the chief disadvantage of the current practice. At the same time, the proposed simple method also aims at preserving all the advantages of the present design control procedure.

PDM does not in any way increase system capability. It does, however, allow optimal use of the system capabilities by improving the accuracy and completeness of the system model.

II. REVIEW OF PRESENT POLICY FOR THE DESIGN CONTROL OF DEEP SPACE TELECOMMUNICATION SYSTEMS

In order to put the proposed model in proper perspective, we first review the current sum-of-adverse-tolerances procedure and criterion. In addition to giving a sketch of its historical background and explaining its technique, it is our aim to pinpoint its advantages and disadvantages. Since the current practice has its merits, we should not simply replace it with a new one which perhaps removes its deficiencies. Indeed, this would be trading away a successful design control procedure and criterion for an untested one. Hence, the proposed method must be a simple and practical alternative which preserves most if not all of these advantages while removing its disadvantages.

It is to be made clear as to when the design criterion is used in a project. A project in general can be broken into roughly the following phases:

(1) Pre-project conceptual design,

(2) Mission and system design,

(3) Detail design, fabrication, and test,

(4) System test,

(5) Launch operations,

(6) Cruise operations,

(7) Encounter operations,

(8) Post-encounter operations.

Though telecommunication link predicts are continually being updated from one mission phase to another, a good model of design uncertainties is most important during the pre-project conceptual design phase when planners must make project commitments such as encounter performance. It is at this stage that a good model must be used to assist in performing various tradeoffs in order to make proper judgment and decisions.

II-1. THE COMMUNICATION EQUATION AND DESIGN CONTROL TABLE

General equations used for the computation of performance are derived from the basic equations for communications in the medium between spacecraft and ground stations. The communication link margin is computed using an equation of the following form:*

$$y = y_1 y_2 \ldots y_K \tag{2-1}$$

where y_i, $i=1,2,\ldots,K$ are parameters of the communication link such as total transmitting power, transmitting antenna gain, receiving antenna gain, loss due to absorption in the transmission medium, polarization loss, circuit loss, space loss, etc. The overall telecommunications system consists of a large number of parameters in product form. Hence, expressed in the dB domain, it becomes a sum of these parameters, i.e.,

$$x = x_1 + x_2 \ldots + x_K \tag{2-2}$$

*This equation is presented in its general form rather than spelling out its detail components. Different types of communication links have different components but the form of this equation remains unchanged.

where

$$x = 10 \log_{10} y \tag{2-3}$$

and

$$x_i = 10 \log_{10} y_i \quad , \ i=1,2,\ldots,K \tag{2-4}$$

For managing the system design, it is most convenient to put this in tabular form with these parameters as entries. This table is referred to as the Design Control Table (DCT). All of the factors that contribute to system performance are listed in the order that one would find in tracing a signal through the system. As an example, the Mariner-Venus-Mercury '73 high data rate telemetry link DCT is shown in Table 2-1. This link is used as an example throughout this report.

II-2. THE PRESENT POLICY: SUM-OF-ADVERSE-TOLERANCES CRITERION

In the design of its telecommunications systems, the JPL has used a deterministic worst case procedure and criterion for selecting the signal-to-noise-ratio margins. This method was formalized in the early days of space exploration in a JPL internal document which we produce in Appendix 1. A more recent policy statement concerning telecommunication system design control is included in Appendix 2.

To every parameter in the DCT, a design value along with its favorable and adverse tolerances is assigned by designers. These tolerances are used not as a hidden safety margin of each parameter; rather, they reflect probable uncertainties, including measurement tolerance, manufacturing tolerance, environment tolerance, drift and aging of elements, parameter modeling errors, etc.

The performance of the entire link is computed by linearly summing in the dB domain the design values, the favorable tolerances, and the adverse tolerances. These values indicate the range of expected link margin values. Since the system adverse uncertainty is obtained by summing all the adverse tolerances in the link, this method has been referred to as the sum-of-adverse-tolerances method. The design value of the link signal-to-noise ratio (SNR) must exceed the minimum required SNR by an amount equal to the adverse tolerance in order to provide the

TABLE 2-1

DESIGN CONTROL TABLE (MVM 73 DSS 14-117 KBPS)

	PARAMETERS	DESIGN VALUE	FAV. TOL.	ADV. TOL.
1.	RF POWER	42.34	1.16	-1.46
2.	CIRCUIT LOSS	-.90	.05	-.05
3.	S/C ANTENNA	27.60	.60	-.60
4.	POINTING LOSS	-.20	.00	.00
5.	SPACE LOSS	-263.09	.00	.00
6.	POLARIZATION LOSS	.00	.01	-.01
7.	GROUND ANTENNA GAIN	61.70	.30	-.40
8.	POINTING LOSS	-.03	.00	.00
9.	ATMOSPHERIC LOSS	.00	.00	.00
10.	SYSTEM NOISE SPEC. DENSITY	-186.71	-.94	.77
11.	DATA BIT RATE	50.70	.00	.00
12.	DATA/TOTAL POWER	-.78	.19	-.26
13.	WAVEFORM DISTORTION LOSS	-.20	.05	-.05
14.	RADIO SYSTEM LOSS	-.10	.05	-.05
15.	SUBCARRIER DEMOD. LOSS	-.33	.15	-.15
16.	BIT SYNC. DETECTOR LOSS	-.10	.05	-.05
17.	RECEIVED DATA POWER	-134.09	2.61	-3.08
18.	THRESHOLD PT/N	1.32	.00	.00
19.	THRESHOLD DATA POWER	-134.69	-.94	.77
20.	PERFORMANCE MARGIN	.60	3.55	-3.85

functional performance required by the project under the conditions prescribed by the project with the minimum safety margin necessary to cover design uncertainties.

Let us consider the advantages and disadvantages of the sum-of-adverse-tolerances method. Experience over many lunar and planetary flight projects has demonstrated that it is practical from the point of view of engineering and management. In particular, it:

(1) is a simple management control tool in that it clearly displays the performance uncertainties for all elements of the system.

(2) has a one-to-one correspondence between parameter accounting and equipment performance specifications.

(3) is very simple in computation and concept.

Its disadvantages chiefly are:

(1) overly conservative; it is extremely unlikely that all parameters operate at their adverse tolerance limits simultaneously, and

(2) incomplete performance specification; the probability of achieving any specific parameter value is not specified. Consequently, cost tradeoff and risk assessment cannot be systematically performed. This, indeed, is the biggest deficiency of the sum-of-adverse-tolerances method.

Since the current practice has its merits, simply replacing it with a new one which perhaps removes its disadvantages is not entirely satisfactory. Indeed, this would be trading away a successful design criterion for an untested one. Hence, we must look for a simple practical alternative which preserves most, if not all, of its advantages while removing its disadvantages.

III. PROBABILITY DENSITY FUNCTIONS FOR LINK PARAMETERS

Though the adverse tolerance value is a deterministic value, it could be interpreted statistically as a parameter with a delta probability density function (pdf). If all parameters in the telecommunications link have delta probability density functions, then indeed the total link performance uncertainty is also one with delta probability density function. This is saying that the uncertainty of the link margin is at this sum-of-adverse-tolerances value with probability one. Of course, this is not true in reality. Past deep space missions have indicated that other values were achieved. This sum-of-adverse-tolerances value represents the lower performance bound in the absence of failure. Therefore, this method does not make optimum use of the system capabilities. Is there an alternative?

Based on JPL's experience and knowledge, it is logical and entirely possible to estimate a probability density function for each parameter in the telecommunications link. Two natural questions arise. The first is what probability density functions should we assume for these link parameters? The second is what do we do with these probability density functions once they are available? Actually, these two questions must be dealt with together since the answer to one depends explicitly on the answer to the other.

Even though we have had many missions since 1958, and many hardware measurements have been made for all these link parameters, the number of data points is in the order of tens, some even in the hundreds; still it is not sufficient to form empirical pdf's. Moreoever, system design has been continually improved along with the state-of-the-art as technology progresses. Earlier measurements may have little current significance. The approach taken here is to use data only from the most recent Mariner class spacecraft, not to generate empirical pdf's, but to guide us in choosing the general shapes and types of simple pdf's. Simplicity of form is important for computational purposes; dependence of form on empirical data is important for accuracy.

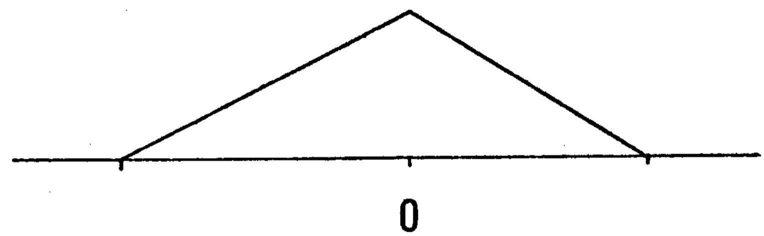
Data from MM'69, MM'71, MVM'73 and VO'75 are gathered from References 1 through 26. These data shed some light as to what the general reasonable shapes of the pdf's of the link parameter uncertainties are. We have made the following choices as shown in Table 3-1. These pdf's are normalized to their design values; hence they represent the uncertainties about the design values. An example is given in Appendix 3 to illustrate how these data were used in selecting pdf shapes.

We reiterate that only the general shape of a parameter distribution is given. Its distribution range depends on the particular application. As more information is available in the future, these pdf's can be modified accordingly.

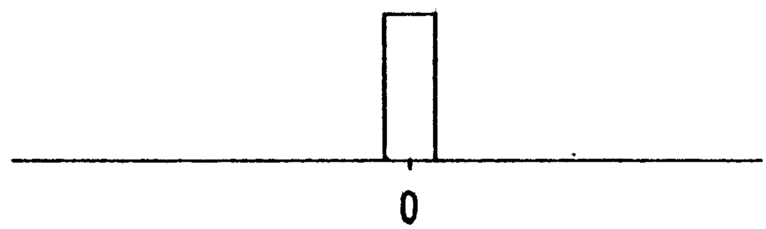
TABLE 3-1

LINK PARAMETERS DISTRIBUTIONS

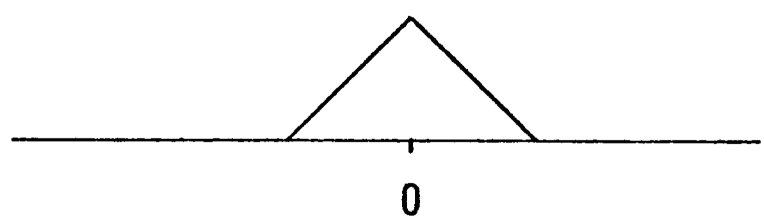
1. RF POWER



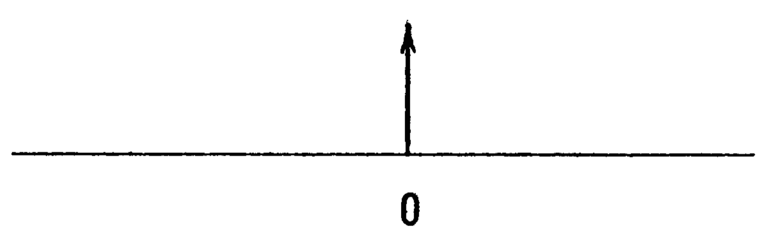
2. CIRCUIT LOSS



3. ANTENNA GAIN
& POINTING LOSS



4. SPACE LOSS



5. GROUND ANTENNA GAIN,
AND POLARIZATION &
POINTING LOSSES

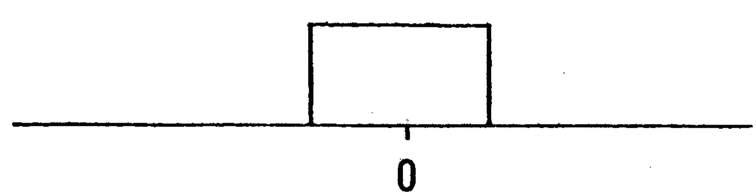
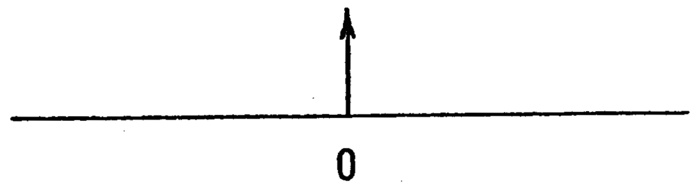
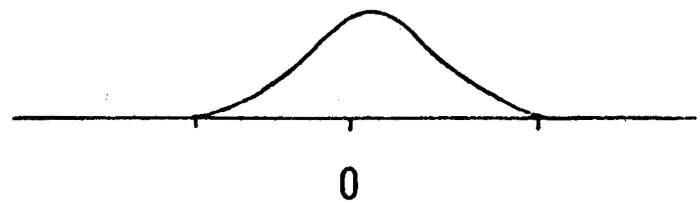


TABLE 3-1 (continued)

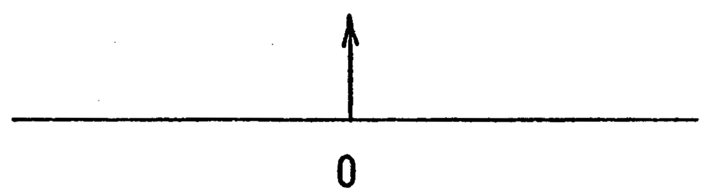
6. ATMOSPHERIC LOSS



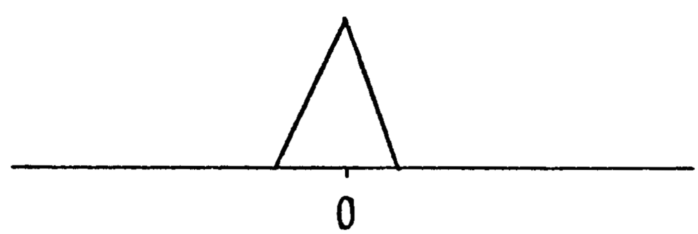
7. SYSTEM NOISE SPECTRAL DENSITY



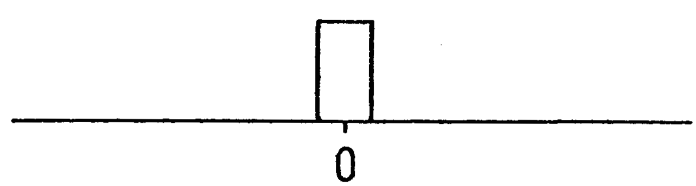
8. DATA BIT RATE



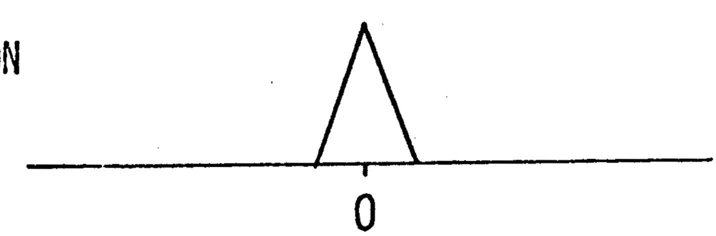
9. DATA POWER/ TOTAL POWER



10. WAVEFORM DISTORTION, AND RADIO LOSS



11. SUBCARRIER DEMODULATION LOSS & BIT SYNC. DETECTOR LOSS



The ground station system parameters are continually being improved. Hence, it is reasonable to assume their uncertainties are due to measurement inaccuracy, station-to-station variation, and operation environment changes.

IV. PROBABILITY DISTRIBUTION METHOD (PDM) IN TELECOMMUNICATIONS LINK DESIGN

This section gives a step-by-step outline of the proposed method. These steps are illustrated with an example.

Step 1

To every parameter in the Design Control Table (DCT), assign

(a) a design value,

(b) its favorable tolerance, and

(c) its adverse tolerance.

As an example, a DCT of the MVM'73 high data rate telemetry link shown in Table 2-1 is used. Note that this step is exactly the same procedure one uses with the sum-of-adverse-tolerances criterion.

Step 2

Gather parameters in the DCT into independent groups, as shown in Table 4-1.

Step 3

Within each group, linearly sum the design values, the favorable and adverse tolerances so that there is only one design value with its associated favorable tolerance and adverse tolerance for each group, as shown in Table 4-1.

Step 4

Based on results in Section III, assign a probability density function for each group with its favorable and adverse values as the probability density function limits. This is illustrated in Table 4-2.

In case a probability density function is non-zero over the entire real line such as the Gaussian density function, use the absolute sum

TABLE 4-1

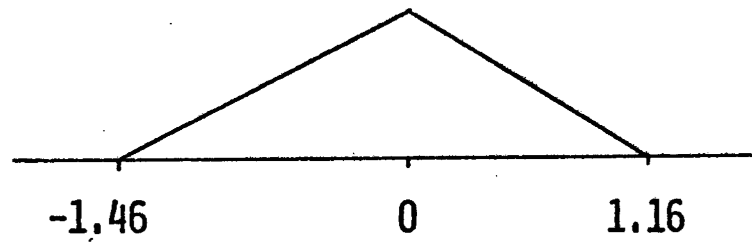
INDEPENDENT GROUPS OF LINK PARAMETERS

	INDEPENDENT GROUPS	DESIGN VALUE	FAV. TOL.	ADV. TOL.
1.	RF POWER	42.34	1.16	-1.46
2.	CIRCUIT LOSS	-.90	.05	-.05
3.	S/C ANTENNA POINTING LOSS	27.60 -.20	.60	-.60
4.	SPACE LOSS	-263.09	.00	.00
5.	POLARIZATION LOSS GROUND ANTENNA GAIN POINTING LOSS	.00 61.70 -.03	.31	-.41
6.	ATMOSPHERIC LOSS	.00	.00	.00
7.	SYSTEM NOISE SPEC. DENSITY	-186.71	-.94	.77
8.	DATA BIT RATE	50.70	.00	.00
9.	DATA/TOTAL POWER	-.78	.19	-.26
10.	WAVEFORM DISTORTION LOSS RADIO SYSTEM LOSS	-.20 -.10	.10	-.10
11.	SUBCARRIER DEMOD. LOSS BIT SYNC DETECTOR LOSS	-.33 -.10	.20	-.20
	RECEIVED DATA POWER	-134.09		
	THRESHOLD PT/N	1.32		
	THRESHOLD DATA POWER	-134.69		
	PERFORMANCE MARGIN	.60		

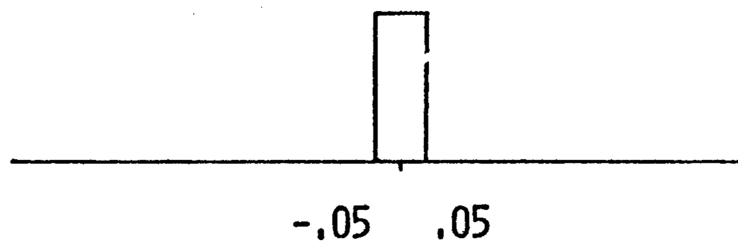
TABLE 4-2

MVM'73 117 KBPS LINK PARAMETERS DISTRIBUTIONS

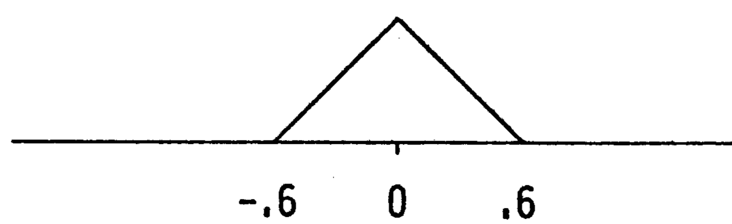
1. RF POWER



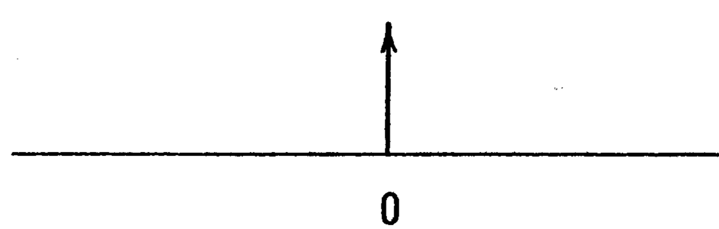
2. CIRCUIT LOSS



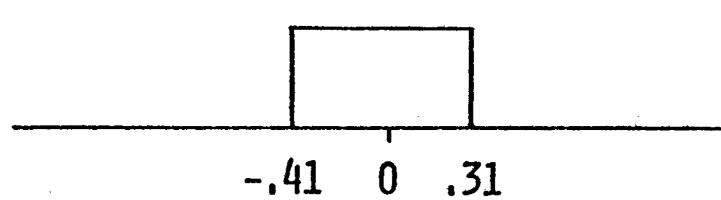
3. ANTENNA GAIN & POINTING LOSS



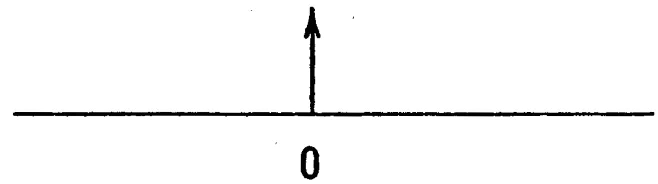
4. SPACE LOSS



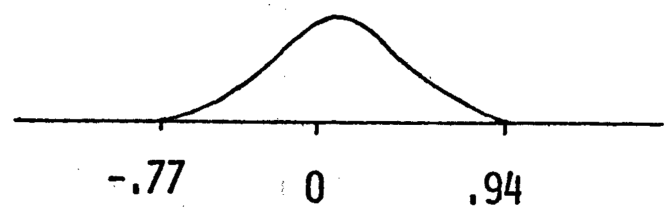
5. GROUND ANTENNA GAIN, AND POLARIZATION & POINTING LOSSES



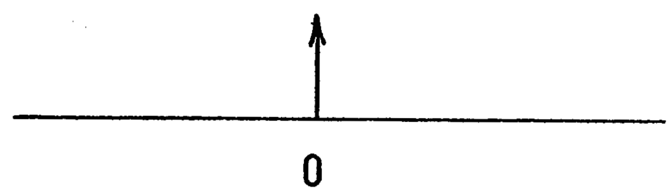
6. ATMOSPHERIC LOSS



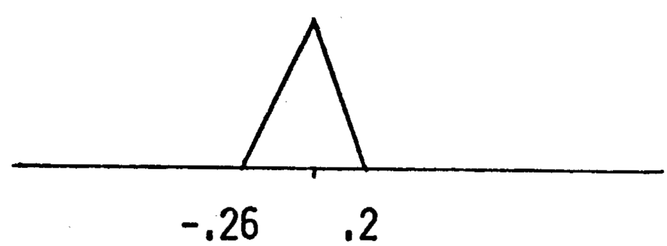
7. SYSTEM NOISE
SPECTRAL DENSITY



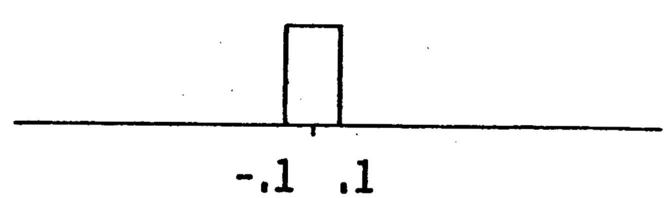
8. DATA BIT RATE



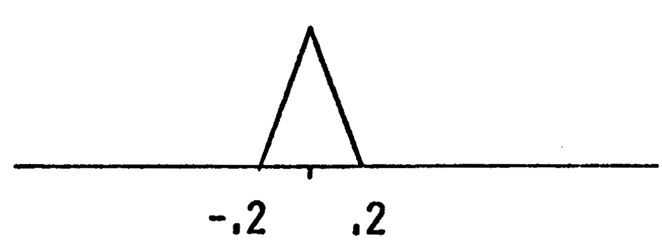
9. DATA POWER/
TOTAL POWER



10. WAVEFORM DISTORTION,
AND RADIO LOSS



11. SUBCARRIER DEMODULATION
LOSS & BIT SYNC.
DETECTOR LOSS



of its favorable and adverse tolerances as its 6σ measure.

Step 5

Since the overall link consists of K independent random variables formed in Step 2 above, based on the Central Limit Theorem (Ref. 27) the overall system performance margin tolerance is well approximated by a Gaussian distribution.

(a) Compute, for each independent group, its mean and variance, i.e. m_i and σ_i^2 for the i-th group, where i=1, 2, ..., K.

(b) Using results in (a), calculate for the link, its mean and variance

$$m = \sum_{i=1}^{K} m_i, \tag{4-1}$$

and

$$\sigma^2 = \sum_{i=1}^{K} \sigma_i^2 \tag{4-2}$$

(c) The probability density function of the link margin is

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left\{- \frac{(x-m)^2}{2\sigma^2}\right\} dx \tag{4-3}$$

And its probability distribution is

$$P(y) = \frac{1}{\sqrt{2\pi\sigma^2}} \int_{-\infty}^{y} \exp\left\{- \frac{(x-m)^2}{2\sigma^2}\right\} dx \tag{4-4}$$

Based on this information, it can be stated that, for example, the link performance will not deviate from its mean margin m by more than 3σ with probability 0.99. This 3σ value is used as an uncertainty measure for the link margin.

Using our example, numerical results are obtained and summarized in Table 4-3 , while its probability density and distribution functions are depicted in Figure 4-1. It is certainly true that a precise probability density function of the overall link margin can be obtained by convolving the pdf's of the K independnet random variables. However, the link margin tolerance distribution is well approximated by a Gaussian distribution by invoking the central limit

TABLE 4-3

LINK MARGIN DISTRIBUTION CALCULATION

$M_1 = -.100$	$\sigma_1^2 = .475$
$M_2 = .000$	$\sigma_2^2 = .001$
$M_3 = .000$	$\sigma_3^2 = .100$
$M_4 = .000$	$\sigma_4^2 = .000$
$M_5 = -.050$	$\sigma_5^2 = .043$
$M_6 = .000$	$\sigma_6^2 = .000$
$M_7 = .085$	$\sigma_7^2 = .081$
$M_8 = .000$	$\sigma_8^2 = .000$
$M_9 = -.030$	$\sigma_9^2 = .015$
$M_{10} = .000$	$\sigma_{10}^2 = .003$
$M_{11} = .000$	$\sigma_{11}^2 = .011$
$M = -.095$	$\sigma^2 = .73$
	$\sigma = .85$
	$3\sigma = 2.56$

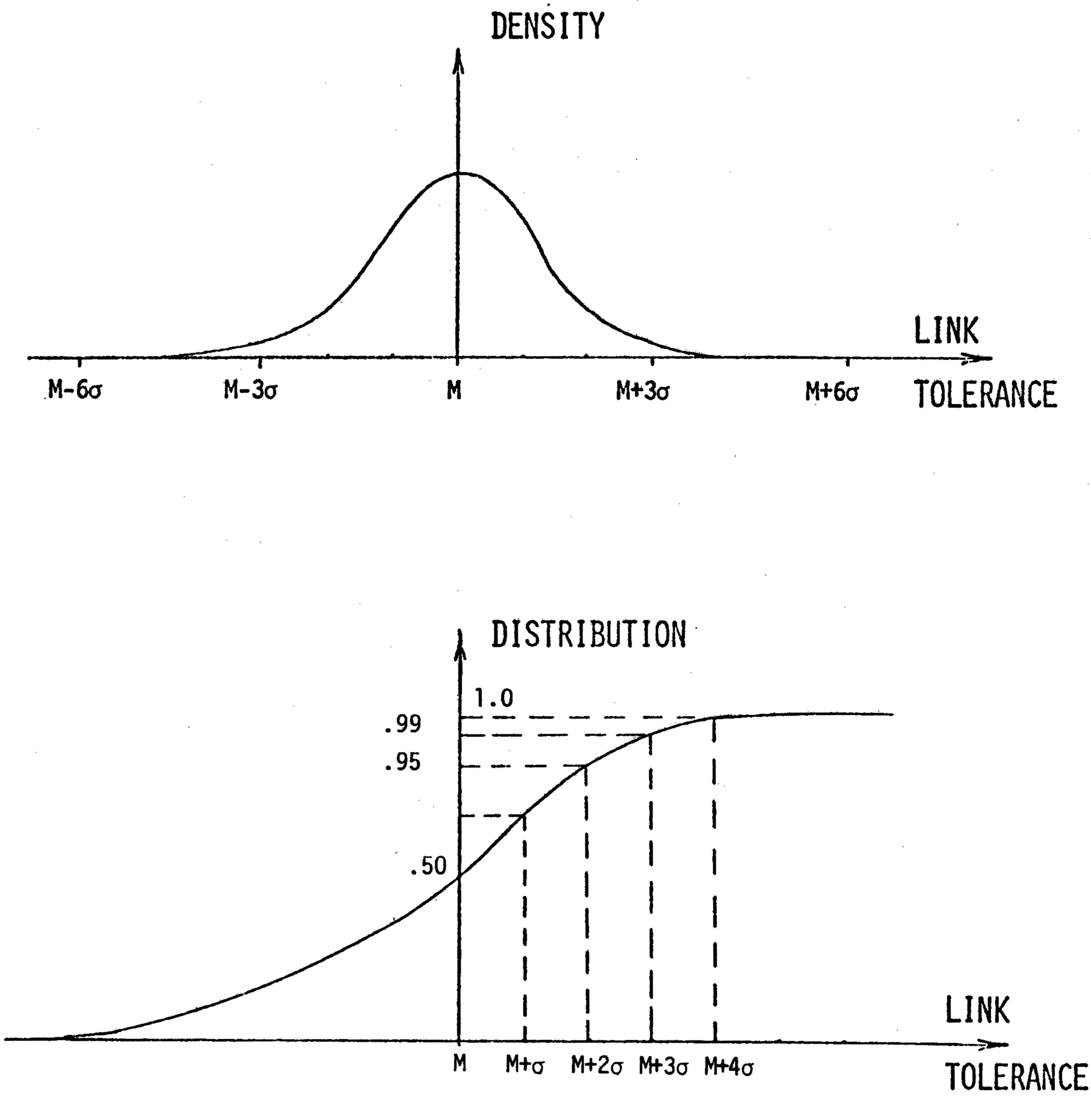


FIGURE 4-1

LINK PERFORMANCE DISTRIBUTION

theorem. This tremendously simplifies the computational complexity to the point that hand calculation is indeed practical. Moreoever, the pdf's of the K independent random variables were only estimated. It seems difficult to justify using tedious convolution to achieve a precise solution based on imprecise information if an approximation is indeed satisfactory. A more worthwhile effort would be making a more accurate estimation of the pdf's of the K independent random variables.

V. COMPARATIVE ANALYSIS

A sketch of historical background and the use of current sum-of-adverse-tolerances design criterion has been presented thus far along with motivation and technique of the PDM. Had PDM existed and been applied in past projects, what would its performance be as compared with the sum-of-adverse-tolerances criterion?

A comparative analysis is performed. Its results are summarized in Table 5-1. The first column shows the recent missions MM'69, MM'71, MVM'73 and VO'75 which are chosen for comparison. The second column shows the magnitude of the sum-of-adverse-tolerances for these missions. The third column shows the 3σ performance uncertainty using the PDM.* The last column shows the difference between the encounter telecommunication link performance value and its preliminary design value. It is shown that, for example, the MM'69 spacecraft performed 1.3 dB and 1.0 dB better than preliminary design value. These deviations are well within the PDM 3σ tolerances.

VI. CONCLUSIONS

The Probability Distribution Method (PDM) described in this report possesses several distinctive features.

First, it preserves the simplicity of the DCT format and its use as a management design control tool. Since we have not changed in any way the corresponding favorable and adverse tolerances assigned to every parameter in the DCT,

*Detail computation is omitted since it is straightforward by following Section IV of this report.

TABLE 5-1

PERFORMANCE COMPARISON

	SUM-OF-ADVERSE-TOLERANCES (dB)	PROBABILITY DISTRIBUTION METHOD, 3σ UNCERTAINTY (dB)	PREDICTION DEVIATION* AT ENCOUNTER (dB)
MM69	-4.48	-3.53	1.3 / 1.0
MM71	-3.32	-2.07	0.1
VM73	-3.85	-2.65	1.08
VO75	-3.26	-2.05	--

*PREDICTION DEVIATION = ENCOUNTER VALUE - EARLY DESIGN VALUE hardware specification and qualification have not been affected. Subsystem engineers proceed with their business as always.

Second, the telecommunication link margin probability density function presents the probability of achieving any particular value of link performance. Hence, we can proceed to assess performance risk and other tradeoffs when we desire to do so.

Third, PDM is computationally simple. It is indeed practical.

Fourth, while the sum-of-adverse-tolerances criterion is based on conservative engineering judgment, PDM is based on sound theoretical framework.

Finally, and most important, performance predictions based on PDM are in excellent agreement with available data.

These distinct characteristics of PDM demonstrate that it is a practical approach which removes the chief disadvantages in addition to preserving all the advantages of the current design control technique. PDM allows optimal use of telecommunication system capabilities by improving the accuracy and completeness of the system model.

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APPENDIX 1

COMMUNICATION DESIGN CONTROL TABLE

JET PROPULSION LABORATORY INTEROFFICE MEMO

TO: Section Chiefs, Group Leaders and Engineers of Division 33

March 20, 1961

FROM: E. Rechtin

SUBJECT: COMMUNICATIONS DESIGN CONTROL TABLE

I. PURPOSE

Close design control of deep space communications is important because improper assignment of margins can lead either to failure or extravagant overdesign. The difference between failure and over-extravagant design is often no more than a few decibels for deep space communications. There must be a consistency of ground rules and clear understanding of what contingencies, if any, are present in the estimates of each contributor. It is not only necessary to know the nominal design values of a particular component, it is also necessary to know the tolerances on this value. From a purely management standpoint, it is necessary to have a clear assignment of responsibility for each element of the communication system. And finally, it is necessary to have unambiguous definition of the communication system margin. The criterion for deciding whether the margin is sufficient may well be controversial, since it is based upon engineering judgment; however, the criterion itself must be clearly understood.

II. CONTENT OF COMMUNICATION DESIGN CONTROL TABLE

SYSTEM: Mariner D Date: May 18, 1966

	Parameter	Nominal Design Value	Tolerance	Signature	Notes
A.	Transmitter Power	44 dbm	+1 -2 db	LWRandolph	(a)
.					
.					
.					
.					
D.	Propagation Loss	-280 db	+0 -5 db	PDPotter	(b)
E.	Detector Threshold	- 8 db	+1 -1 db	RZToukdarian	
.					
.					
.					
.					
K.	Signal/Threshold	10 db	+2 -8	RPMathison	

(a) Uncertainty due to lack of test data as of 16 March 1961.
(b) Uncertainty due to lack of knowledge of Martian ionosphere.

The above table was designed to accomplish the purposes of communication design control. Each significant parameter of the communication system is entered into the table with its nominal design value and its tolerance. The correctness of these values is attested to by the signature of the cognizant engineer. Whenever the design value or the tolerances are known to be unusual or require certain qualifying remarks, they are fully footnoted. There are a variety of reasons that tolerances may be greater than one would desire. One reason might be an uncertainty due to lack of propagation information which it is the purpose of the flight experiment to determine. (This latter reason was a crucial determinate in the design of the Jupiter flame effects test, for example.)

Most of the parameters in a communication system are well understood and largely self-explanatory. A remark is worthwhile, however, on the subject of detector threshold. Detector threshold is defined as the signal to noise ratio required at the detector to achieve proper performance. The threshold is seldom if ever, zero db. The threshold values used for "proper performance" is admittedly less absolute than most of the other nominal design values. However, this threshold can and should be determined to within one decibel by a combination of theoretical and experimental measurements. For example, the detector threshold for phaselock circuits, to the best of our present knowledge, is 8 decibels ± 1 decibel. The detector threshold for FMFB detection with typical modulation indices appears to be 12 to 15 decibels. Whatever the assigned value of the threshold, it is the intention of this parameter to specify the performance of a particular piece of equipment; it is <u>not</u> the purpose of this parameter to act as a hidden "safety margin."

The final parameter in the table is the ratio of signal level to threshold. The design value of this parameter is derived from the appropriate summation of the nominal design values. The tolerances on this parameter are determined by summing the positive tolerances separately and the negative tolerances separately. If properly done, there is no hidden safety margin on the nominal design value. All of the uncertainties in component performance, whether due to engineering uncertainties or skepticism over subcontractor performance, are included in the tolerance column.

The table is as correct as engineering estimates can make it. There should be no "safety margins" hidden within the table. Each contributing cognizant engineer must appreciate that all values must be accurate; it is almost as damaging to overall performance to estimate low as to estimate high.

III. USE OF THE COMMUNICATIONS DESIGN CONTROL TABLE

Until a much better criterion can be established, the criterion for an acceptable communications system will be that the design value of the signal to threshold ratio is equal or greater than its negative tolerance.

It can be argued that this criterion is too conservative. For many communications systems, this might be the case. For deep space communication systems with their very close tolerances, however, the debate is largely academic. The sum of the negative tolerances must be a relatively small number for this type of communications, in any case. If the sum of the negative tolerances is too large, then it should be the effort of all cognizant individuals to reduce these tolerances as rapidly as possible by gathering the necessary theoretical and experimental information. A large negative tolerance implies that the communication system itself is not very well understood, a condition which is not acceptable for reliable, primary, deep space communications.

The table is intended as a management tool as well as a description of the communication system itself. For example, tolerances on the gains of spacecraft antennas are notoriously difficult to keep small. To keep antenna tolerances as small as might be desired, it is essential to make exceptionally accurate pattern measurements using a very good antenna range. It was as a direct consequence of this line of argument that our unique antenna range was established on the hills overlooking JPL. It may well turn out in the future that extensive testing programs for certain components are justified on precisely the same grounds. Needless to say, living within one's specified tolerances is the mark of a qualified engineer.

It is intended that a communications design control table be kept current in the DSIF Program Office for every communication system for which the Telecommunications Division is responsible. The tables will be compiled by R. P. Mathison of Section 334.

ER/bdm

APPENDIX 2

POLICY FOR THE DESIGN OF DEEP SPACE TELECOMMUNICATION SYSTEMS

JET PROPULSION LABORATORY

INTEROFFICE MEMO
No. 3300-70-620

TO: Distribution

October 28, 1970

FROM: R. Stevens R Stevens

SUBJECT: Policy for the Design of Deep Space Telecommunication Systems.

A copy of the Subject policy is attached. It is in effect.

RS:mh

POLICY FOR THE DESIGN OF DEEP SPACE TELECOMMUNICATION SYSTEMS

This policy establishes the principal design criterion for a JPL telecommunication system. It also identifies Telecommunications Division goals for improved use and reduced uncertainty of telecommunication system performance for deep space missions

The performance of the telecommunication system and its major subsystem elements will be specified by a design value and by favorable and adverse tolerances which cover design uncertainties. The principal design criterion for a telecommunication system used for JPL flight project support is that the system provide the functional performance required by the project under the conditions prescribed by the project with the minimum safety margin necessary to cover design uncertainties. This criterion is met when the design value of received signal level exceeds the design value of required signal level on a (decibel) sum of adverse tolerances basis.

A single document, "The (Project Name) Telecommunication Design Control," governing the telecommunication system design and performance for the project shall be issued, normally by the project. The development and maintenance of the document shall be the responsibility of the Telecommunication System Cognizant Engineer for each project. The document shall be prepared according to established procedures and updated as required to meet project needs. DSN commitments of ground station performance in the document are controlled by the DSN.

Non-JPL flight projects supported by the DSN will be encouraged to use the identical criterion for telecommunication system design.

The Telecommunications Division will work continuously toward:

- Improving the accuracy of the design value specifying link performance, particularly during the design phase of a project.
- Reducing the tolerance of link parameters.
- Reducing the number of link elements with separately assigned tolerances.
- Meeting the design-value as opposed to adverse tolerance performance.
- Taking advantage of link performance which exceeds the adverse tolerance value (by multiple data rate or other multi-mode designs).
- Separate specification of the spacecraft and ground portions of the link.

Concurred: W. H. Bayley

W. H. Bayley, ALDTDA

J. N. James

J. N. James, ALDTD

R J Parks

R. J. Parks, ALDFP

R. Stevens

R. Stevens, Manager
Telecommunications Division

October 14, 1970

APPENDIX 3

PARAMETER PROBABILITY DENSITY SELECTION: AN EXAMPLE

APPENDIX 3

PARAMETER PROBABILITY DENSITY SELECTION: AN EXAMPLE

This appendix gives an example of how the data from recent Mariner class spacecrafts (References 1 through 26) were used to guide the choice of general shapes of simple probability density functions of the link parameters.

For each link parameter, and for each project, we gather its design value and the measured values of actual hardware. Since we are only interested in the deviations from the design value, we normalize these measured values with respect to the design value, i. e., we subtract the design value from the measured values to obtain its deviations. For example, for the spacecraft antenna gain, we have sixteen measured values along with four design values for the four projects MM'69, MM'71, MVM'73 and VO'75. After normalized with respect to their respective design values, we have sixteen samples of deviation or uncertainty. Figure A-1 displays the number of samples vs. the magnitude of deviations which are quantized to 0.1 dB in this case.

Since there are only 16 measurements for this link parameter, it is not sufficient to form an empirical pdf. Our aim here is to use these data to guide us in choosing a reasonably simple pdf. In this case, a simple pdf is a triangular function which is superimposed on Figure A-1 to show reasonable fitness with our data.

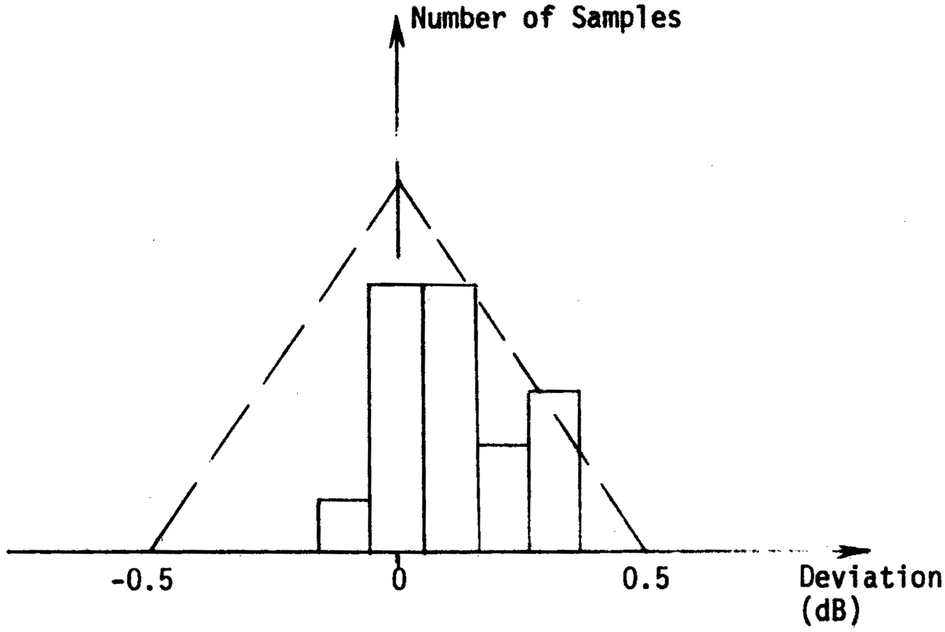

FIGURE A-1
SPACECRAFT ANTENNA GAIN:
NUMBER OF SAMPLES VS. DEVIATION

NASA — JPL — Coml., L.A., Calif.